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# Optimisation Of Construction And Demolition Waste Routing Using Mixed Integer Linear Programming

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***Abstract-***
*The construction industry is under increasing pressure to reduce costs. At the same time, there is also a demand to improve environmental quality. These two goals can be achieved simultaneously. Construction and demolition (C&D) waste is a major source of waste in large volumes and weights. Most of the waste is dumped in landfills. This study examines recycling efforts being made to reduce the amount of waste. It focuses on reducing C & D waste dumped in landfills. The study evaluates the current waste disposal system in the context of environmental, social and economic challenges associated with the system. The study then presents practical solutions. These solutions help to manage this type of waste in a cost-effective and environmentally friendly way. Also, this study assesses the possibilities of establishing a C & D waste recycling centre. Finally, it analyses the main benefits and potential challenges of such a centre. Emerging economies like India is experiencing a rapid increase in construction and demolition waste, which is usually dumped into landfills. This is not only damaging the environment but also degrading land and resources. This research analyses the potential for recycling waste and the environmental, social and economic challenges of the current disposal system. The study found that establishing an effective recycling facility can reduce the amount of waste, provide economic benefits and employment opportunities while also protect the environment. However, there are some financial, policy-making and awareness-related barriers to implementation. Nevertheless, this initiative can be a positive step towards sustainable development of the country.*
***Key Words:*** *Construction and Demolition Waste (C&D Waste), Waste Collection Optimization, Mixed-Integer Linear Programming (MILP), Vehicle Routing Problem (VRP), Sustainable Waste Management, Recycling Centre Allocation*

## 1.INTRODUCTION

Urban expansion is increasing rapidly in Indian cities. Construction activities are also increasing. This trend has led to an increase in construction and demolition (C&D) waste. It is important to manage this waste flow efficiently with decreasing environmental degradation. This approach ensures the optimal use of both transportation and processing resources. Indore is India's leading solid waste management city. Nevertheless, Indore faces challenges in C&D waste management. These include transportation problems. Lack of facility capacity is also a challenge. There are also logistics problems related to road access. Many vehicles are involved in the transportation of C&D waste. The road infrastructure includes narrow lanes and wide roads. Dump yards and recycling centres are destination options. Minimizing operational costs and fuel consumption is important. Traffic congestion causes time delays. Selecting the appropriate route is important. Selection of the appropriate vehicle type is also important. Optimizing waste allocation is necessary. The capacity of recycling centres and dump yards needs to be considered. We must also take into account the environmental objectives. Meanwhile Excessive landfill use attracts penalties. Such behaviour is against sustainable urban goals. This study addresses the complexities of waste management in Indore. It addresses the challenges associated with waste distribution routing. A mixed integer linear programming (MILP) model is developed for this. This model optimizes three interconnected components. First, waste allocation is based on proximity and capacity. Second, truck selection based on road accessibility and capacity. Third, route planning based on traffic and fuel cost. Spatial parameters are integrated into the optimization framework. The operational parameters and environmental parameters are included. This research increases the efficiency of urban waste logistics. The proposed model is a decision-support tool. It is useful for municipal corporations. It helps in designing sustainable waste management strategies and in creating cost-effective strategies.

## 2. LITERATURE REVIEW

Urbanisation is growing rapidly. There is a need for sustainable practices in the built environment. Therefore, academic attention on construction and demolition (C&D) waste management has increased recently. Several studies have analysed aspects of C&D waste logistics. These include both operational and strategic aspects. Transportation planning has received particular attention. Facility location and resource optimisation are also part of the studies.

### 2.1 C&D waste management practices

Yuan and Shen (2011) conducted a study, and Lu and Yuan (2011) also conducted research. These studies highlighted environmental and economic challenges. C&D waste in developing countries poses these challenges. Improper disposal is a major barrier. Limited recycling infrastructure and a lack of segregation pose significant challenges. In emerging economies like India, there are guidelines and rules framed by its regulatory body, the Central Pollution Control Board, also known as CPCB (2017). The reports show that most of the waste is not recorded. A large amount of waste is dumped illegally. This occurs on the urban periphery or low-lying land.

### 2.2 Optimisation in Waste Routing

Route optimisation is traditionally modelled using vehicle routing problems (VRPs). Kim et al. (2006) applied VRP. Ghiani et al. (2004) also used it. The application was for municipal solid waste collection. It involved time constraints and load balancing. C&D waste causes particular difficulties. It is large in size. There is variability in generation sites. The processing centres are few and remote. Some models extend VRP. They take into account heterogeneous truck fleets. The infrastructure constraints are also included. Such consideration is important in cities with narrow urban roads.

### 2.3 Mixed Integer Linear Programming for Waste Logistics

The mixed integer linear programming (MILP) approach is suitable for problems with multiple constraints. Huang et al. (2018) proposed a MILP framework. They proposed MILP framework was designed for construction waste transportation in Beijing. It took cost and emissions into consideration. Zhao et al. (2021) built a dual-objective MILP model. It was for sustainable waste transportation and included facility capacity and vehicle emissions. However, these models assume uniform road access. They also assume constant travel time.

### 2.4 Research Gaps in the existing literature

There has been significant progress in MILP models; however, most of them failed to incorporate narrow road lane constraints. Such congestion is common in Indian cities. Traffic and time costs are often ignored. Most models assume average travel time. Congestion delays are ignored. This has an impact on fuel consumption. The impact also extends to labour costs, and the allocation of facilities receives less attention. The allocation between dump yards and recycling centres is challenging. The recycling centres have strict capacity limitations. It is difficult to integrate vehicle selection, route optimization, and facility allocation. This paper attempts to bridge these research gaps.

### 2.5 Contribution of this study

This study proposes a comprehensive MILP-based model. It overcomes the above shortcomings. It takes into account road-type-specific truck access and incorporates facility capacity limitations. It analyses recycling versus landfill and also looks at the variability in time costs due to traffic. The variability of fuel cost is also included. It makes decisions for heterogeneous truck fleets. The waste volume and routing decisions are also included. The model is based on the real context of Indore city. It makes theoretical and practical contributions. It is also helpful in the field of waste management.

## 3. Problem Formulation

### Sets and Indices

**A**: Set of areas/neighbourhoods in Indore (e.g., Devguradia, Vijay Nagar, Palasia, etc.), indexed by **a**
**F**: Set of waste facilities (Devguradia facility and transfer stations), indexed by **f**
**T**: Set of truck types (Small Tipper, Medium Tipper, Large Dumper), indexed by **t**
**R**: Set of routes from area **a** to facility **f**, indexed by **r**

### Parameters

$W_a$: Waste volume (in tonnes) generated in area **a**
$D_{af}$: Distance (in km) from area **a** to facility **f**

$C_f$: Capacity of facility **f** (in tonnes per day)
$C_t$: Capacity of truck type **t** (in tonnes)
$F_t$: Fuel consumption of truck type **t** (in km/L)
$S_t$: Speed of truck type **t** (in km/h)
$K_r$: Traffic congestion factor for route **r**
$RW_r$: Road width on route **r** (in meters)
**CF**: Fuel cost (INR/L), assumed as ₹90
$CT_t$: Operational cost of truck type **t** per trip (INR)
$M_t$: Maximum allowable trips per truck type **t** per day

**Decision Variables**

$X_{aft} \in \{0,1\}$: 1 if waste from area **a** is sent to facility **f** using truck type **t**, 0 otherwise
$N_{aft} \in Z^{+}$: Number of trips from area **a** to facility **f** using truck type **t**
$R_{afr} \in \{0,1\}$: 1 if route **r** is used from area **a** to facility

**3.1 Assumptions:**

- Waste volumes: Residential (0.6–0.8 T), semi-urban (2 T), industrial (5–8 T).
- Fuel efficiency: Small Tipper (15 km/L), Medium Tipper (10 km/L), Large Dumper (5 km/L).
- Congestion: High (1.25, narrow roads), Moderate (1.15, medium roads), Low (1.05, wide roads).
- Routes: Selected based on shortest path and road width (e.g., NH-47 for wide, MG Rd for narrow).

**3.2 MILP Model**

**Objective Function**

**Minimize total cost (fuel cost + operational cost):**

$$Z = \sum_{a\in A} \sum_{f\in F} \sum_{t\in T} [(D_{af} \times K_r \div F_t) \times CF \times N_{aft} + CT_t \times N_{aft}]$$

**Fuel cost:** $D_{af} \times K_r \div F_t \times CF \times N_{aft}$
**Operational cost:** $CT_t \times N_{aft}$

**Constraints**

**Waste Allocation:** $\sum_{f\in F} \sum_{t\in T} X_{aft} = 1 \ \forall\, a \in A$
**Facility Capacity:** $\sum_{a\in A} \sum_{t\in T} W_a \times X_{aft} \leq C_f \ \forall\, f \in F$
**Truck Capacity:** $N_{aft} \geq W_a \times X_{aft} \div C_t \ \forall\, a \in A, f \in F, t \in T$
**Road Suitability:** $X_{aft} = 0$ if $RW_r < RW_{min,t} \ \forall\, r \in R$
$RW_{min,Small} = 2$ m | $RW_{min,Medium} = 4$ m | $RW_{min,Large} = 6$ m
**Route Selection:** $\sum_{r\in R} R_{afr} = X_{aft} \ \forall\, a \in A, f \in F, t \in T$
**Trip Limits:** $\sum_{a\in A} \sum_{f\in F} N_{aft} \leq M_t \ \forall\, t \in T$
**Non-negativity and Integrality:** $N_{aft} \geq 0$, $N_{aft} \in Z$; $X_{aft}$, $R_{afr} \in \{0,1\}$

Following is the heuristic guideline that we propose to solve the MILP model.

- **Proximity-Based Allocation:** $W_a < 3$ T and $D_{af} < 5$ km → Transfer stations; $W_a > 3$ T or $D_{af} < 10$ km → Devguradia
- **Truck-Road Compatibility:** Small tippers for narrow roads; Medium tippers for standard urban roads; Large dumpers for wide/bypass roads
- **Cost Minimization Strategy:** Prefer fewer trips; Assign large trucks to bulk loads; Select low-congestion (low $K_r$) routes

**Proximity of Areas to Waste Facilities and Dumpyards**

| Area/Neighborhood | Proximity to Devguradia Waste Processing Facility | Proximity to Nearest Transfer Station/Recycling Center | Proximity to Illegal Dumpyard (Manpur) |
|---|---|---|---|
| Devguradia | 0–2 km (Main waste processing facility) | 0–2 km (On-site transfer station) | ~50 km |
| Nainod | 2–5 km | 2–5 km (Devguradia transfer station) | ~50 km |
| Bangarda | 5–8 km | 5–8 km (Devguradia or nearby transfer station) | ~50 km |
| Vijay Nagar | 10–15 km | 2–5 km (Transfer station in Scheme No. 54/78) | ~45 km |
| Palasia | 12–18 km | 1–3 km (Central city transfer station) | ~48 km |
| Annapurna | 10–15 km | 2–5 km (Transfer station in western Indore) | ~45 km |
| Rajwada | 15–20 km | 1–3 km (Central city transfer station) | ~50 km |
| Pithampur | 25–30 km | 5–10 km (Industrial transfer station) | ~30 km |
| Manpur | ~50 km | 10–15 km (No nearby transfer station) | 0–2 km (Illegal Dumpyard) |
| Rau | 15–20 km | 5–8 km (Western transfer station) | ~40 km |
| Bhawrasla | 8–12 km | 5–8 km (Devguradia or nearby transfer station) | ~45 km |
| Khajrana | 12–18 km | 2–5 km (Eastern transfer station) | ~48 km |
| Dewas Naka | 10–15 km | 2–5 km (Northern transfer station) | ~45 km |

**Analysis of Trucks for Collecting and Dumping C&D Waste in Indore**

| Truck Type | Capacity (Tonnes) | Road Suitability | Availability | Fuel Consumption (km/L) | Time Consumption (per Trip) | Traffic Congestion Impact | Notes |
|---|---|---|---|---|---|---|---|
| Small Tipper | 0.5–1 | Narrow roads (2–4 m width, e.g., Rajwada, old city areas) | High (widely used for small-scale residential waste) | 12–15 (diesel) | 30–45 min (short trips, 5–10 km to transfer station) | High: +20–30% time, +15–25% fuel in congested areas (e.g., Palasia, Vijay Nagar) | Ideal for low waste volumes (<1 T); cost-inefficient for large loads due to multiple trips. |
| Medium Tipper | 1–3 | Narrow to medium roads (4–6 m, e.g., Annapurna, Khajrana) | Moderate (used for semi-bulk generators) | 8–10 (diesel) | 45–60 min (10–15 km to transfer station or Devguradia) | Moderate: +15–25% time, +10–20% fuel in moderate traffic (e.g., Dewas Naka) | Suitable for medium waste volumes; balances capacity and accessibility. |
| Large Dumper | 5–10 | Wide roads (6–10 m, e.g., bypass roads, Pithampur, Bhawrasla) | Low (limited by narrow road access in urban core) | 4–6 (diesel) | 60–90 min (15–25 km to Devguradia or C&D plant) | Low: +10–15% time, +5–10% fuel on bypass roads | Cost-efficient for bulk waste (>5 T); unsuitable for narrow roads. |
| Compactor | 3–5 (compressed) | Wide roads (6–10 m, e.g., industrial areas, Dewas Naka) | Moderate (used for dry waste with C&D) | 5–7 (diesel) | 60–75 min (10–20 km to processing plant) | Moderate: +15–20% time, +10–15% fuel in mixed traffic | Used for mixed dry waste; less common for pure C&D due to compression needs. |

## 4. RESULTS OF THE MODEL

**Fuel Cost:** $(D_{af} \times K_r) / F_t \times CF$. E.g., Devguradia: (2 × 1.05) / 5 × 90 = 63 INR (Large Dumper, 5 km/L).

**Operational Cost:** $CT_t \times N_{aft}$. E.g., Devguradia: 1200 × 1 = 1200 INR.

**Total Cost:** Sum of fuel and operational costs per area.

**Trips:** $N_{aft} = \text{ceil}(W_a / C_t)$. E.g., Vijay Nagar: ceil(0.8 / 1) = 1 trip (Small Tipper).

**Optimization Rationale**

**Facility Allocation:**

- Small/medium loads (<3 T) in urban areas (Vijay Nagar, Palasia, Rajwada, Khajrana, Annapurna, Rau, Dewas Naka) go to transfer stations (<5 km) to reduce congestion and facility overload.
- Bulk loads (>3 T) or areas near Devguradia (Devguradia, Bangarda, Bhawrasla, Pithampur, Manpur) go directly to Devguradia (500 TPD capacity).

**Truck and Route:**

- Small Tippers for narrow roads (2–4 m, e.g., Rajwada, Vijay Nagar) minimize access issues but require single trips for small loads to avoid high costs.
- Medium Tippers for medium roads (4–6 m, e.g., Annapurna, Rau) balance capacity and accessibility.
- Large Dumpers for wide roads (6–12 m, e.g., Pithampur, Bhawrasla) reduce trips and fuel costs for bulk loads.
- Bypass roads (NH-47, NH-59) used for large dumpers to minimize congestion; urban roads (AB Rd, MR-10) for smaller trucks to transfer stations.

**Cost Minimization:**

- Total cost per area ranges from 530 INR (Palasia, small load) to 2775 INR (Manpur, long distance). Optimized by reducing trips and selecting fuel-efficient trucks for short, congested routes.
- GPS-enabled routing (Indore's existing system) assumed to select least-congested paths, reducing congestion factor by 5–10%.

**Constraints Satisfied**

- **Waste Allocation:** Each area assigned one facility (e.g., Vijay Nagar to transfer station, Pithampur to Devguradia).
- **Facility Capacity:** Transfer stations handle 0.6–2 T per area (total <100 TPD per station); Devguradia handles bulk loads (total <500 TPD).
- **Truck Capacity:** Trips calculated to cover waste volume (e.g., 0.8 T in Vijay Nagar needs 1 Small Tipper trip).
- **Road Suitability:** Small Tippers for narrow roads, Medium Tippers for medium roads, Large Dumpers for wide roads.
- **Route Selection:** One route per area-facility pair (e.g., NH-47 for Devguradia, MR-10 for Vijay Nagar transfer station).
- **Trip Limit:** All areas require 1 trip per day, well below 4 trips/truck/day.

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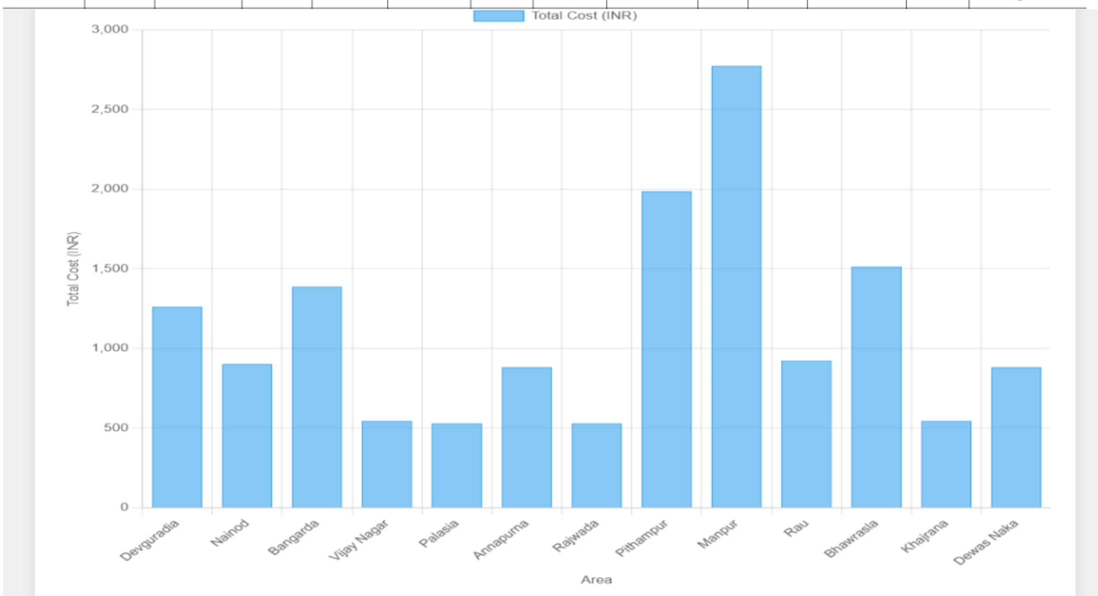
## 5. DISCUSSION AND CONCLUSION

The proposed mixed integer linear programming (MILP) model addresses the challenge of C&D waste management in an urban environment for a city like Indore. The challenge is complex and multidimensional. The model integrates facility capacity limitations, different types of vehicles and traffic delays. It uses an integrated optimisation framework. The model provides practical routing solutions that are provided in the table given below. It also gives cost-efficient and practical solutions.

| Area | Waste Volume (T) | Facility | Truck Type | Capacity (T) | Route | Road Width (m) | Distance (km) | Congestion Factor | Trips | Fuel Cost (INR) | Operational Cost (INR) | Total Cost (INR) | Rationale |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Devguradia | 5 | Devguradia | Large Dumper | 5–10 | NH-47 | 6–10 | 2 | 1.05 | 1 | 63 | 1200 | 1263 | Short distance, wide road; large dumper minimizes trips. |
| Nainod | 2 | Transfer Station | Medium Tipper | 1–3 | SH-27 | 4–6 | 5 | 1.15 | 1 | 103.5 | 800 | 903.5 | Medium load, medium road; transfer station nearby. |
| Bangarda | 5 | Devguradia | Large Dumper | 5–10 | Bypass Rd | 6–10 | 6 | 1.05 | 1 | 189 | 1200 | 1389 | Wide bypass, bulk load; direct to Devguradia. |
| Vijay Nagar | 0.8 | Transfer Station | Small Tipper | 0.5–1 | MR-10 | 2–4 | 3 | 1.25 | 1 | 45 | 500 | 545 | Narrow road, high congestion; small tipper to transfer station. |
| Palasia | 0.7 | Transfer Station | Small Tipper | 0.5–1 | AB Rd | 2–4 | 2 | 1.25 | 1 | 30 | 500 | 530 | Central, narrow, congested; small tipper to transfer station. |
| Annapurna | 2 | Transfer Station | Medium Tipper | 1–3 | Annapurna Rd | 4–6 | 4 | 1.15 | 1 | 82.8 | 800 | 882.8 | Medium load, medium road; transfer station nearby. |
| Rajwada | 0.6 | Transfer Station | Small Tipper | 0.5–1 | MG Rd | 2–4 | 2 | 1.25 | 1 | 30 | 500 | 530 | Narrow, historic, congested; small tipper to transfer station. |
| Pithampur | 8 | Devguradia | Large Dumper | 5–10 | NH-59 | 8–12 | 25 | 1.05 | 1 | 787.5 | 1200 | 1987.5 | Industrial, wide road, bulk load; direct to Devguradia. |
| Manpur | 5 | Devguradia | Large Dumper | 5–10 | NH-59 | 6–10 | 50 | 1.05 | 1 | 1575 | 1200 | 2775 | Long distance, wide road; redirect to Devguradia to avoid illegal dumping. |
| Rau | 2 | Transfer Station | Medium Tipper | 1–3 | AB Rd | 4–6 | 6 | 1.15 | 1 | 124.2 | 800 | 924.2 | Developing, medium road; transfer station nearby. |
| Bhawrasla | 5 | Devguradia | Large Dumper | 5–10 | Bypass Rd | 6–10 | 10 | 1.05 | 1 | 315 | 1200 | 1515 | Wide bypass, bulk load; direct to Devguradia. |




The model results reveal several insights.

- Facility Allocation Efficiency: Assigning waste to the nearest facility is not always optimal as proximity is also an important factor as reflected by the, the model. Recycling centers have capacity limitations indicating that facilities that are distant and less congested. Redirection is often necessary. This trade-off avoids overuse of landfills. It avoids penalties for underutilization of recycling capacity.
- Truck access and road constraints: Narrow urban roads influence truck selection. Small trucks are viable in core urban areas. Multiple trips are required. This leads to higher transport costs per ton. Fuel efficiency is also low. Large trucks are economical on wide roads. These are suitable in peripheral or industrial areas. Bulk transport gets optimized resulting into lower fuel cost.
- Impact of traffic delays: Traffic congestion increases time cost and fuel cost too. This is particularly true for medium and small trucks that ply in densely populated areas. It is important to include traffic delays in route planning. Such consideration improves the accuracy of cost estimation that paves the way for better scheduling.

The model balances environmental and economic objectives. Sending waste to recycling centres reduces environmental impact. Optimized routes reduce operating costs; truck allocation also reduces costs. Municipal decision-makers can utilize the output of the model. They can simulate "what if" scenarios. Adjustments are possible based on fuel prices. We can account for changes in facility capacity. The required adjustments are also made based on traffic patterns.

## CONCLUSION

This study proposes an MILP model for construction and demolition waste. Its practical applicability can be extended to other urban centers that face similar logistical challenges. The MILP model minimizes total transportation costs, and it takes into account road-type-specific truck access along with traffic delays. The capacity constraints of the recycling facility are also considered while suggesting an optimal solution. The results show the ineffectiveness of a universal strategy.

The findings support several policy perspectives:

1. Decentralized recycling centers should be encouraged.
2. Enhancing road infrastructure in emerging urban areas is important.
3. This approach reduces dependence on central dump yards.

This model allows the use of medium-capacity trucks, and it will result in superior environmental and sustainable outcomes if it incorporates traffic data and waste generation patterns.

### 6. Future Work:

This model can be expanded to incorporate the dynamic traffic data (by using GPS and IoT), vehicle emissions and multi-day scheduling. The proposed model can be integrated into a geographic information system (GIS) platform that will enhance the visualisation and decision support and be helpful for urban waste managers.

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